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(71) Applicant (*for all designated States except US*): ASEA BROWN BOVERI AB [SE/SE]; S-721 83 Västerås (SE).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): ERIKSSON, Jan-Erik [SE/SE]; Egilsvägen 60, S-723 55 Västerås (SE). HALLEFÄLT, Magnus [SE/SE]; Mackstavägen 9, S-640 45 Kvicksund (SE). KOLLBERG, Sten [SE/SE]; Nordanbygatan 58, S-722 23 Västerås (SE). PETERSOHN, Carl [SE/SE]; Svartensgatan 8, S-116 20 Stockholm (SE). TALLBÄCK, Göte [SE/SE]; Bandygatan 12, S-722 40 Västerås (SE).

(74) Agent: WILEN, Anders; Dr Ludwig Brann Patentbyrå AB, P.O. Box 1344, Drottninggatan 7, S-751 43 Uppsala (SE).

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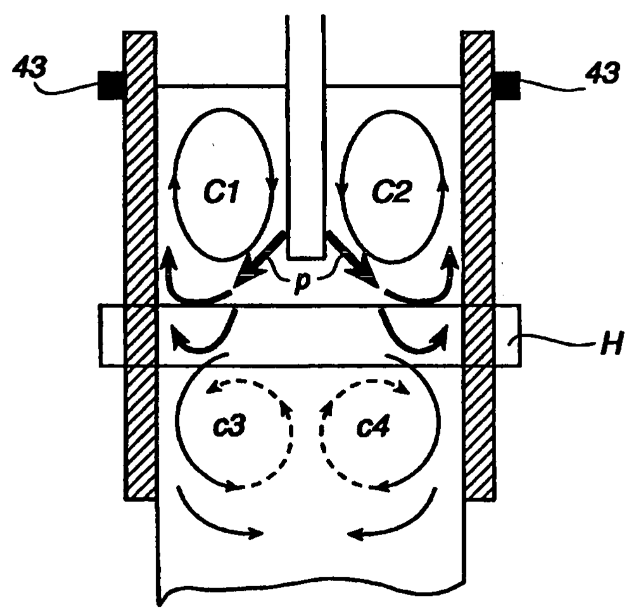
(54) Title: METHOD AND DEVICE FOR CONTROL OF METAL FLOW DURING CONTINUOUS CASTING USING ELECTROMAGNETIC FIELDS

(57) Abstract

A method and a device for continuous or semi-continuous casting of metal. A primary flow (P) of hot metallic melt supplied into a mold is acted upon by at least one static or periodically low-frequency magnetic field to brake and split the primary flow and form a controlled secondary flow pattern in the non-solidified parts of the cast strand. The magnetic flux density of the magnetic field is controlled based on casting conditions. The secondary flow (M, U, C1, C2, c3, c4, G1, G2, g3, g4, O1, O2, o3, o4) in the mold is monitored throughout the casting and upon detection of a change in the flow, information on the detected change monitored flow is fed into a control unit (44) where the change is evaluated and the magnetic flux density is regulated based on this evaluation to maintain or adjust the controlled secondary flow.



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# METHOD AND DEVICE FOR CONTROL OF METAL FLOW DURING CONTINUOUS CASTING USING ELECTROMAGNETIC FIELDS

## TECHNICAL FIELD

The present invention relates to a method for casting of metals. The present invention relates in particular to a method for continuous or semi-continuous casting in a mold, wherein the flow of metal in the non-solidified parts of the strand cast is acted on and controlled by at least one static or periodically low-frequency magnetic field applied to act upon the molten metal in the mold during casting. The present invention also relates to a device for carrying out the invented method.

## BACKGROUND ART

In a process for continuous or semi-continuous casting a metallic melt is chilled and formed into an elongated strand. The strand is dependent of its cross-section dimensions called a billet, a bloom or a slab. A primary flow of hot metal is during casting supplied to a chilled mold wherein the metal is cooled and at least partly solidified into an elongated strand. The cooled and partly solidified strand continuously leaves the mold. At the point where the strand leaves the mold it comprises at least a mechanically self-supporting skin surrounding a non-solidified center. The chilled mold is open at both its ends in the casting direction and preferably associated with means for supporting the mold and means for supplying coolant to the mold and the support. The chilled mold preferably comprises four mold plates, preferable made of copper or other material with a suitable heat conductivity. The support means are preferably beams with internal channels for supply of coolant, normally water, thus such support beams are often called water beams. The water beams are arranged around and in good thermal contact with the chilled mold to fulfill its double function of supporting and cooling the mold.

The hot primary metal flow is supplied either through a nozzle submerged in the melt, closed casting, or through a free tapping jet, open casting. These two alternative

methods create separate flow situations and effects how and where the magnetic field(s) is applied. If the hot primary metal flow is allowed to enter the mold in an uncontrolled manner it will penetrate deep in the cast-strand, which is likely to negatively effect the quality and productivity. Non-metallic particles and/or gas might be drawn in and entrapped in the solidified strand. An uncontrolled hot metal flow in the strand might also cause flaws in the internal structure of the cast strand. Also a deep penetration of the hot primary flow might cause a partial remelt of the solidified skin such that melt penetrates the skin beneath the mold causing severe disturbance and long down-time for repair. To avoid or minimize these problems and improve the production conditions can according to the disclosure in European Patent Document EP-A1-0 040 383 one or more static magnetic fields be applied to act on the incoming primary flow of hot melt in the mold to brake the incoming flow and split up the primary flow and thereby is a controlled secondary flow created in the molten parts of the strand. The magnetic field is applied by a magnetic brake, comprising one or more magnets. Favorably an electromagnetic device, i.e. a device comprising one or more winding such as a multi-turn coil wound around a magnetic core, are used. Such an electromagnetic brake device is called an electromagnetic brake, an EMBR.

According to the disclosure of the European Patent document EP-B1-0 401 504 magnetic fields shall be applied to act in two levels, arranged one after the other in the casting direction, during casting with a submerged entry nozzle, closed casting. The magnets comprises poles having a magnetic band area covering essentially the whole width of the cast strand and one first level is arranged above and one second level below the outlet ports of a submerged nozzle. Further EP-B1-0 401 504 teaches that the magnetic flux should be adopted to the casting conditions, i.e. the strand or mold dimensions and casting speed. The magnetic flux and the magnetic flux distribution shall be adopted to ensure a sufficient heat transport to the meniscus to avoid freezing while at the same time the flow velocity at the meniscus shall be limited and controlled so that the removal of gas or inclusions from the melt is not put at risk. A high uncontrolled flow velocity at the meniscus might also cause mold powder to be drawn down into the melt. It is also suggested in this document that an optimum range exists for the flow velocity at the meniscus, see figure 9 of said document. It is suggested in this document that the magnetic flux density over the mold shall be adopted before a casting

operation based on the specific conditions assumed to prevail during the coming cast operation. To accomplish this EP-B1-0 401 504 suggest a mechanical magnetic flux controlling device which is arranged to move the magnetic poles in essentially their axial direction to change the distance between the poles comprised in one cooperation pair and arranged facing each other on opposite side of the mold, see figure 15 and column 8, lines 34 to 50. Such a mechanical magnetic flux controlling device must however be extremely rigid to accomplish a stable magnetic flux density, especially when subject to the large magnetic forces prevailing under operation of the brake while at the same time being capable of small movements to accomplish the adjusting changes in flux density required as the flux density has a high sensitivity to changes in the distance between the poles. Such mechanical magnetic flux density controlling device will require a combination of heavy gauge material, rigid construction and small movements in the direction of the magnetically field, which will be hard and costly to accomplish. According to one alternative embodiment the mechanical flux density device is formed by partial substitution of the poles by non-magnetic material such as stainless steel, i.e. by a change in the configuration of the poles and thereby an alteration of the pattern of the magnetic flux in the mold before each cast. Similar ideas, as to the configuration of the poles, is also discussed in other documents such as EP -A1-577 831 and WO92/12814. The patent document WO96/26029 teaches the application of magnetic fields in further levels including one or more levels at or just downstream the exit end of the mold to further improve the control of the secondary flow in the mold. Flux density controlling devices of these types based on reconfiguration and/or movements of the poles by mechanical means must be complemented with means for securing the magnet core or partial cores to withstand the magnetic forces and is thus intended for preseting the magnetic flux density and adopted to casting conditions predicted to prevail during a forthcoming casting and it will include costly and elaborative development work to use such devices for on-line regulation of the magnetic flux density.

According to the European Patent Document EP-A1-0 707 909 the flow velocity at the meniscus shall be set within a range of 0.20 - 0.40 m/sec for a continuous casting method wherein a primary flow is supplied to mold through a nozzle capable of controlling the incoming flow and wherein a static magnetic field having a substantially

uniform magnetic flux density distribution over the whole width of the mold is applied to act on the metal in the mold. It further teaches that the flow at the meniscus can be held within this range by setting several parameters such as;

- the angle of the port(s) in the submerged nozzle;
- the position of the nozzle port(s) within the mold;
- the position of the magnetic field; and
- the magnetic flux density.

The angle and position of the nozzle port(s) as well as the position of the magnetic field(s) are determined and preset before the start of casting and the magnetic flux is controlled according to one out of two different algorithms. The choice of algorithm to be used is dependent on the position of the magnetic field relative the primary flow, i.e. if the primary flow out of the nozzle port(s) traverses a magnetic brake field or not before hitting the side-wall. The algorithm(s) are based on one measured value only, the flow velocity at the meniscus when no magnetic field is applied, i.e. a historical value measured at an earlier casting or possible at the start of the casting if the casting are started with the brake off. The other values of the algorithms are all preset. The values included are the mold width and thickness which truly is constant and the average flow velocity of molten steel through the nozzle port(s), i.e. the primary flow, which is treated as a constant value or possible as a predetermined function of time. Thus will in fact the magnetic flux density also according to this method be preset as it will be based on predetermined and preset parameters only and the control will not account for any change in the actual casting conditions or a dynamically progressing process and will consequently not be capable of adjusting the flux density on-line based on a change in the actual flow. Examples of parameters or conditions which effect the secondary flow and are likely to change during casting is, the ferrostatic pressure at the nozzle port(s), nozzle angle(s) or nozzle dimensions due to erosion or clogging, the superheat in the primary flow, i.e. its temperature relative the melting point, chill at meniscus, level of meniscus in mold. The primary flow might also have to be adopted due to a change in casting speed or other separately controlled production parameter.

## OBJECTS OF THE INVENTION

It is a primary object of the present invention to provide a method for continuous casting of metal wherein the flow in the mold is controlled during casting by an on-line regulation of the magnetic flux density of a magnetic field applied to act on the metal to brake and split the incoming primary flow of hot metal and formed a controlled secondary flow pattern in the mold. The on-line regulation shall be provided throughout essentially the whole casting and be based on the actual casting conditions or operating parameters prevailing in the mold or effecting the conditions in the mold at that moment to provide a cast product with a minimum of defects produced at same or improved productivity.

As the flow at the meniscus has shown critical for both removal of impurities, trapping of mold powder and gas and indicative of the flow situation prevailing in the mold it is also an object of the present invention to monitor the flow at the meniscus throughout the casting by direct or indirect methods and include any change detected in this flow in the on-line regulating of the magnetic flux density to ensure a minimum of trapping or accumulation of non-metallic inclusions, mold powder or gas in the cast products. It is further an object of the present invention to provide a device for carrying out the invented method.

Other advantages of the present invention will became apparent from the description of the invention and the preferred embodiments of the invention. Including its capabilities to provide an improved and controlled flow pattern throughout the casting also when one or more parameters change and the thereby increased capability to, over a wide range of operating parameters, mold dimensions, metal compositions etc., control the solidification conditions in the cast product, conditions for removal of no-metallic impurities from the cast product and the entrapment of mold powder or gas in the cast products, so that even when one or more of these parameters changes for whatever reason during casting the casting conditions can remain essentially stable or be adjusted to be within preferred limits.

## SUMMARY OF THE INVENTION

To achieve this the present invention suggest a casting method according to the preamble of claim 1, which is characterized by the features of the characterizing part of claim

1. In a continuous or semi-continuous casting method according to the present invention a primary flow of hot metallic melt is supplied into a mold and at least one static or periodically low-frequency magnetic field is applied to act on the melt in the mold. One or more magnetic fields are arranged to brake and split the primary flow and form a controlled secondary flow pattern in the non-solidified parts of the cast strand. To achieve the desired secondary flow the magnetic flux density of the magnetic field is regulated based on casting conditions. To accomplish the primary object of the invention the secondary flow in the mold is monitored throughout the casting and any detected change in the monitored flow is fed into a control unit where the change is evaluated. The magnetic flux density is thereafter regulated based on this evaluation to maintain or adjust the controlled secondary flow. Preferably the flow velocity of the secondary flow in at least one specific point in the mold is measured continuously throughout essentially the whole casting. As an alternative to the continuous measurement of the flow velocity the flow velocity can also be discontinuously measured or sampled throughout essentially the whole casting operation. Upon detection of any change in the flow will information on this change, irrespective if it is detected by continuously measurement or sampling, be fed into the control unit where it is evaluated. The magnetic flux density is thereafter regulated based on this evaluation.

A device for carrying out the invented method for continuous or semi-continuous casting of metals comprises a mold for forming a cast strand, means for supply of a primary flow of a hot metallic melt to the mold and magnetic means arranged to apply at least one magnetic field to act upon the metal in the mold and is according to the present invention arranged with the magnetic means associated with a control unit. The control unit is associated to detection means, which are arranged to monitor metal flow in the mold and detect any changes in said flow. Upon detection of a change in the casting conditions or in the flow information on the change is fed into the control unit which comprises evaluation means to evaluate said detected change and control means to regulate the magnetic flux density of the magnetic field based on the evaluation of the detected change in said flow.

The detection means can be any known sensor or device for direct or indirect determination of the flow velocity in a hot metallic melt, such as flow sensors based on eddy-

current technology or comprising a permanent magnet, temperature sensors by which a temperature profile of e.g. one of the narrow sides or the meniscus can be monitored, a level sensing device for determination and supervision of level height and profile of a melt surface in a mold, the meniscus. Suitable detection means will be exemplified and described in more detail in the following.

The control unit comprises means, preferably in the form of an electronic device with soft-ware in the form of a algorithm, statistical model or multivariate data-analysis for processing of casting parameters and information from the detection means on flow, and means for regulating the magnetic flux density based on the result of said processing. According to one embodiment of the invention the control unit is arranged within a neural network comprising electronic means for supervision and control of further steps and devices associated with the casting operation. The control unit also comprises means for the regulation of the magnetic flux density of the magnetic brake. For an electromagnetic brake this is best accomplished by control of the amperage fed to the windings in the electromagnets of the electromagnetic brake. This is accomplished by any current limiting device controlled by an out-signal from the control unit. Alternatively for an electromagnet which is connected to a voltage source the voltage can be controlled by the out-signal from the control unit thus indirectly controlling the amperage of the current in the magnet windings. The control unit will be further exemplified in the following. Further developments of the invention are characterized by the features of the additional claims.

As the flow conditions can vary within the mold has it in some cases been shown desirable to monitor the flow at two or more locations within the mold and also to apply the magnetic fields in such a way that the magnetic flux density of one magnetic field can be regulated separately and independently of any other magnetic fields based on the flow prevailing in the part of the mold on which the magnetic field is applied to act. The typical situation is that for a slab mold wide two wide sides and a tapping point in the center of the mold, at least one magnetic circuit is arranged to apply at least one magnetic to act on the melt in each half of the mold, i.e. the mold is, in the casting direction, split into two control zones, each control zone comprising a half of the mold and is disposed on each side of a

plane comprising the center line of the wide sides. The flow at the meniscus is measured directly or indirectly for both control zone, i.e. mold halves and the left control zone sensor is associated with means for regulating the magnetic flux density of a magnetic field acting on the melt in the left half of the mold and a right control sensor is associated with means for regulating the magnetic flux density of a magnetic field acting on the melt in the right half of the mold. The mold can, naturally, be divided into zones of any number and shapes where at least one sensor and at least one magnetic flux density regulating means is associated with each zone. Using two control zones ensures that an essentially symmetrical two-loop flow is developed in the upper part of the mold and that the risks of the two-loop flow developing to an unsymmetrical or unbalanced flow showing e.g. marked differences in the flow velocities at the meniscus for the two mold halves, a so called biased flow, or even in the extreme case transforming into an undesired one-loop flow, where the melt flows up along one molds side, across the meniscus to the other side, down and further back across the mold at level with or just downstream the nozzle ports, is essentially eliminated.

According to one embodiment the flow velocity at the meniscus ($v_m$) is monitored or sampled. Upon detection of a change in flow velocity at the meniscus ($v_m$) information on this change is fed into the control unit where it is evaluated. Based on this evaluation that the magnetic flux density is regulated in a suitable way to either maintain the secondary flow pattern or should it be deemed suitable change the flow. According to one preferred embodiment the magnetic flux density is then controlled to maintain or adjust the flow velocity at the meniscus ($v_m$) to be within a predetermined flow velocity range.

According to one alternative embodiment the upwardly directed secondary flow ($v_u$) at one of the molds narrow sides is monitored or sampled. Upon detection of a change in this upwardly directed flow velocity ($v_u$) information on this is fed into the control unit. Based on this evaluation the magnetic flux density is regulated to maintain or adjust the flow velocity of this upwardly directed flow ($v_u$) or, as the flow at the meniscus ($v_m$) is a function of this upwardly directed flow, to maintain or adjust the flow at the meniscus ($v_m$) to be within a predetermined flow velocity range. This flow velocity range will vary with casting speed, nozzle geometry, nozzle immersion depth and when gas is purged the gas flow,

superheat and mold dimensions, but shall for the casting slab using a submerged entry nozzle with side ports and a moderate casting speed normally be held within the range mentioned in the foregoing.

According to one further alternative embodiment the profile of the meniscus, part of this profile or a parameter characterizing it such as the height ($h_w$), location and/or shape of a standing wave, which is generated in the meniscus by the upwardly directed secondary flow at one of the molds narrow sides, is supervised or sampled throughout essentially the whole casting. The profile of the meniscus and especially the standing wave is closely dependent on the upwardly directed flow ($v_u$), as is also, as referred to in the foregoing paragraph, the flow velocity at the meniscus. Therefore can any detected change in the profile such as the height, location or shape of this standing wave be correlated to a flow velocity. Based on such correlation or evaluation the magnetic density is regulated to maintain the standing wave, the flow velocity of the upwardly directed flow and/or the flow velocity at the meniscus within predetermined limits.

According to one preferred embodiment of the present invention the algorithm, statistical model or data-analysis method used for processing the detected changes also comprises parameter values for one or more predetermined parameters out of the following group of parameters;

- mold dimensions,
- nozzle dimensions and nozzle configuration including the angle of the ports,
- dimensions, configuration and position of magnetic poles;
- composition of metal cast;
- composition of mold powder used.

Such a parameter value is included in the algorithm, statistical model or method for data analysis used to evaluate the determined change to the flow and regulate the magnetic flux density of the magnetic field on-line. The parameter is included as a constant value or if relevant as a time-dependent function, which is assumed to vary in a known way over the casting sequence or as a function of any other casting parameter or flow. Examples of

dependent parameters which value can be included in the algorithm, statistical model or method for data-analysis as a function of time or other parameter are;

- changes in primary flow due clogging and/or wear of nozzle;
- superheat of primary flow, i.e. metal upon entry in the mold;
- ferrostatic pressure at nozzle exit.

According to one preferred embodiment of the present invention one or more out of the following group of parameters is monitored or sampled together with the secondary flow during casting;

- superheat of the metal upon entry in mold;
- ferrostatic pressure at nozzle exit;
- flow velocity of primary flow upon exit from nozzle;
- any gas bubbling in mold;
- casting speed;
- mold powder addition rate;
- position of meniscus in mold and relative nozzle port;
- position of nozzle port relative mold;
- position of magnetic field(s) relative meniscus and nozzle ports;
- direction of magnetic field; and
- any other casting parameter deemed critical for the secondary flow and which is likely to change during casting.. Preferably one or more these parameters is supervised or sampled throughout essentially the whole casting process and included on-line in the algorithm, statistical model or method for data analysis used to evaluate the determined change to the flow and regulate the magnetic flux density of the magnetic field on-line. The changes can be due to a time-dependent process or be due to an induced change of the casting conditions. These parameters which are accommodated for in the algorithm, statistical model or method for multivariate data-analysis will thereby effect the on-line regulation of the magnetic flux so that the magnetic flux density can be adopted to these changes and a better control of the secondary flow is accomplished.

Preferably the algorithm, numerical mod l or method for multivariate data-analysis used in addition to the monitored or sampled flow parameters also include further

casting parameters in the form of preset or predetermined constants, predetermined functions as well as monitored or sampled parameter values. Thus will the controlled secondary flow be more stable and well adopted to give the preferred flow pattern for the conditions actual prevailing in the mold.

According to a further embodiment the control unit is also associated to one or more further electromagnetic devices, which are arranged to apply one or more alternating magnetic fields to act upon the melt in the mold or in the strand. Such electromagnetic device are stirrers which can be arranged to act on the melt in the mold or on the melt down-streams of the mold e.g. on the last remaining melt in the so called sump but also high-frequency heaters are used preferably applied to act on the melt adjacent to the meniscus to avoid freezing, melt mold powder and provide good thermal conditions e.g. when casting with low superheat.

The present invention according provides means to adopt the flow and thereby also thermal conditions to achieve the desired cast structure while ensuring the cleanliness of the cast product and same or improved productivity. The embodiments which include monitoring or sampling of further parameters and/or information on induced changes in production parameters are especially favorably as they provide the possibility to, upon the detection of a change in a casting parameter, adopt the magnetic flux density to counteract any disturbance like to come as a result of this change or take measures to minimize such a disturbance known to be the result of such change.

## BRIEF DESCRIPTION OF THE DRAWINGS

Some embodiments of the invention shall in the following be described in more detail while referring to the drawings where;

Figure 1 is a schematic illustration of the top end of one embodiment of a mold for carrying out the invented method, showing the meniscus and a typical secondary flow;

Figures 2 and 3 exemplifies flow patterns obtained with embodiments of the present invention, where an electromagnetic brake is applying magnetic brake fields to act in two

magnetic band areas at two separate levels within a mold and where the primary flow of hot metal enters the mold through side ports of a submerged entry nozzle and at least one magnetic band area is arranged at level or downstream the side-ports.

Figure 4 schematically illustrates a device for carrying-out the method according to one embodiment of the present embodiment comprising a continuous casting mold, an electro-magnetic brake and a control unit for supervising the casting conditions and regulate the brake based on changes in casting conditions.

Figures 5, 6, 7 and 8 exemplifies flow patterns obtained with further embodiments of the present invention, wherein;

Figures 5 and 6 illustrate embodiments where magnetic fields are applied at one level only;

Figure 7 illustrates an embodiment where the present invention is used to stabilize a reversed flow; and

Figure 8 illustrates an embodiment where the flow is monitored separately in each mold half and where the magnetic field acting in one half of the mold is regulated independently of the magnetic field acting in the other half.

DESCRIPTION OF PREFERRED EMBODIMENTS, EXAMPLES.

In figure 1 the top end section of a mold, typical for continuous casting of large slabs, is shown the mold is comprising four chilled mold plates 11, 12 of which only the narrow side plates are shown. The plates are preferably supported by so called water beams, not shown. These water beams also preferably comprises internal cavities or channels for coolants, preferably water. During casting is, according to the embodiment of the present invention shown in figure 1, the primary flow of hot metal supplied through a nozzle 13 submerged in the melt. Alternatively the hot metal can be supplied through a free tapping jet, open casting. The melt is cooled and a partly solidified strand is formed. The strand is continuously extracted from the mold. If the hot primary metal flow is allowed to enter the mold in an uncontrolled manner it will penetrate deep into the cast-strand. Such a deep intrusion in the stand is likely to effect the quality and productivity negatively. An uncontrolled hot metal flow in the cast strand might result in entrapment of non-metallic particles and/or gas in the solidified strand. or cause flaws in the internal structure of the cast strand due to disturbance

of the thermal and mass transport conditions during solidification. A deep penetration of a hot flow might also cause a partial remelt of the solidified skin such that melt penetrates the skin beneath the mold causing severe disturbance and long down-time for repair. According to the method illustrated in figure 1 one or more static magnetic fields have been applied to act on the incoming primary flow of hot melt in the mold to brake the incoming flow and split up the primary flow. Thereby have a controlled flow pattern been created in the molten parts of the strand. According to the method for continuous casting of metal shown the primary flow of metal enters the mold through side ports in a submerged entry nozzle and a secondary develops as this flow is split and hits the narrow side of the mold. The flow in the upper part of the mold is controlled by the magnetic field applied and exhibits an typically an upwardly directed flow up along the narrow side walls U, a flow M along and adjacent to the meniscus 14 and a standing wave 15 which is formed in the meniscus adjacent to the narrow side wall. A reversed secondary flow, see O1 and O2 in figure 7, upwardly directed in the center of the mold and outwards towards the narrow sides at the meniscus, might also develop during special conditions, e.g. when gas is purged through the nozzle to avoid deposition and clogging in the nozzle. The flow M at the meniscus, and especially the velocity of the flow $v_m$, has shown critical for both removal of impurities, trapping of mold powder and gas and indicative of the flow situation prevailing in the mold. It has therefore proven favorable to, according to one embodiment of the present invention, monitor the flow at the meniscus throughout the casting by direct or indirect methods and include any change detected in this flow M in the on-line regulating of the magnetic flux density to ensure a minimum of trapping or accumulation of non-metallic inclusions, mold powder or gas in the cast products. As both the meniscus flow M and the height, position and shape of the standing wave 15 in most situations are dependent on the upwardly directed flow U it has shown possible to base the on-line regulation according to the present invention also on direct or indirect measurements of the flow U or the nature, or location of the standing wave. All these parameters can be monitored continuously or sampled throughout a casting using e.g. devices 43 based on eddy-current technology or comprising a permanent magnet or other devices adopted for determination of flow velocity or levels of a liquid or melt contained within a vessel, such as a mold or a ladle. Thus the on-line regulation according to the present invention favorably comprises the continuous measurement or sampling of any of these

parameters. Hereby it has been proven that the method according to the present invention improves the capabilities to provide a controlled and stable flow pattern throughout the casting and also to provide capabilities to adjust the flow if so desired. The method also exhibits an increased capability to control, stabilize and adjust the in-mold flow during continuous casting based on continuous monitoring or sampling of a plurality of operating parameters and thereby provide improved solidification conditions in the cast product, improved conditions for removal of no-metallic impurities from the cast product and improved conditions for minimizing entrapment of mold powder or gas in the cast products, so that even when one or more of the operating parameters changes for whatever reason during casting the casting conditions can remain essentially stable or be adjusted to be within preferred limits.

The flow pattern illustrated in figure 2 is typically developed for a method where a primary flow p of the hot melt enters the mold through side ports of a submerged entry nozzle a brake is adapted to apply magnetic fields to act on the metal in the mold in;

- a first magnetic band area A at a level with the meniscus or at a level between the meniscus and the side ports; and
- a second magnetic band area B at a level downstream the side ports.

The width of the magnetic band areas covers preferably as shown in figure 2 essentially the whole width of the cast product. This configuration of the magnetic band areas A,B, provides a significant circulating secondary flow C1 and C2 in the top end of the mold, between the two levels of the magnetic band areas A,B, which is monitored by flow sensors 43. Downstream of the second magnetic band area B might also a less stable circulating flow c3 and c4 develop, but the secondary flow is when casting according to the embodiment illustrated in figure 2 characterized by the braking and split of the primary flow caused by magnetic band area B resulting in a stable secondary flow C1 and C2 created by the cooperation of magnetic forces, induced currents and the momentum of the primary flow in the region between the two band areas. In the situation shown in figure 2 is preferably the secondary flow C1 and C2 supervised by monitoring them, using suitable sensors 43 located either at the meniscus, at the narrow side or by monitoring the standing wave. The magnetic flux density is preferably regulated to maintain the flow C1 and C2 within preset limits, but at

times it might prove favorable to regulated the magnetic flux density such that the polarity of one or both magnetic band areas is reversed. By arranging sensors 43 for monitoring the flows C1 and C2 separately the flows C1 and C2 can also be controlled independently provided that the magnetic field forces acting on the melt can be controlled for each half of the mold.

According to an alternative embodiment used in a similar mold and also for closed casting, the magnetic fields is applied to act in;

- a first magnetic band area D at a level with the side ports openings of the submerged entry nozzle; and
- a second magnetic band area E at a level downstream the side ports.

The width of the magnetic band areas D,E covers, also according to this embodiment, essentially the whole width of the cast product. With the configuration of the magnetic band areas D, E as shown in figure 3 a good braking of the primary flow p is obtained in combination with the development of a stable secondary flow G1 and G2 in a region between the band areas D,E which is supplemented by smaller but stable secondary flows g3 and g4 in the upper part of the mold, i.e. above band area D. Also in this situation is preferably the main secondary flow, i.e. G1 and G2 supervised preferably by monitoring it at the narrow side using suitable sensors 45. But also the minor flow at the top end g3 and g4 needs to be monitored using suitable sensors 43. The magnetic flux density of the magnetic field acting in band area D is preferably regulated. Preferably both the flow G1 and G2 and the flow g3 and g4 is maintained within preset limits, but at times it might prove favorable to regulated the magnetic flux density such that the polarity of one or both magnetic band areas is reversed. By arranging sensors 45 for monitoring the flows G1 and G2 separately the flows G1 and G2 can also be controlled independently the mold provided that the magnetic field forces acting on the melt can be controlled for each half of the mold. The same goes for g3 and g4.

The device shown in figure 4 illustrates the essential parts to carry out the invented method. Further to the mold 41 and the brake 42 the device also comprises;

- detection means 43, 45 for supervision of one or more flow parameters in the mold;

- a control unit 44 associated with both the detection means 43,45 and the magnetic means, i.e. the brake 42 or other device capable of regulating the magnetic flux density such as mechanical means for adjusting the distance between the front end of the magnetic core and the mold, or for inserting plates influencing the magnetic field between the magnet and the mold. The mold 41 shown in figure represents also all equipment associated with the mold to enable continuous or semi-continuous casting of one or more cast strand, such as support means, a system for supply and distribution of coolant, means for oscillating the mold, means for supply of hot metal to the mold and the complete casting machine needed for handling of the cast strand downstream of the mold. The brake 42 shown is an electromagnetic brake comprising magnets and associated parts such as a magnetic yoke, not shown, and a power source 421. The brake 42 is arranged and adapted to act upon the melt in the mold in such a way to create a desired secondary flow pattern in the mold. As an alternative to an electromagnetic brake can, provided that a sufficient magnetic flux density can be generated, a brake based on permanent magnets be used. The detection means 43,45 comprises at least sensors for supervision of one or more parameter characterizing the flow to be controlled but comprises further in some preferred embodiments sensors for continuous monitoring or sampling of further casting parameters. Suitable sensors for monitoring or sampling flow parameters is eddy-current based devices or devices comprising a permanent magnet for measurement of flow or levels inside vessel, such devices which are arranged outside the vessel is well-known in the metal industry for other purposes. The input means comprised in the control unit 44 is adapted to receive the signals $x_1$, $x_2$ ..... $x_n$ from the detection means 43 and in some embodiments also further signals y, w, t , u, et cetera from other sensors arranged to monitor or sample one or more casting parameters such as mentioned in the foregoing. In some embodiments the input means are also arranged to receive information $\Delta$, $\Phi$, $\Sigma$, et cetera on preset conditions or parameters. According to some embodiments the input preferably also include means for receiving instructions on how the flow shall be controlled, e.g. within what limits certain parameters shall be maintained, if the flow shall be altered, thus enabling the operator to change the conditions on-line, e.g. enabling a change of direction in the flow by altering the magnetic flux density such that the polarities of the magnetic field(s) is reversed. The control unit 44 is preferably arranged in the form of a conventional electronic device with soft-ware in the form of a algorithm, statistical model or multivariate data-analysis for

processing of information received through the input means such as casting parameters and information from the detection means 43 together with any other received information and based on the result of such processing regulate, through output means comprised in the control unit, the magnetic flux density. According to one embodiment of the invention the control unit 44 and the detection means are arranged within or associated with a neural network comprising electronic means for supervision and control of further steps and devices associated with the casting operation or the whole production in the plant. The out put means comprised in the control unit 44 is adapted to regulate the magnetic flux density of the magnetic brake based on the processing in the control unit 44 of the input which at least comprises information of any change detected in a supervised flow parameter. For an electromagnetic brake the regulation of the magnetic flux density is preferably accomplished by controlling the amperage of the current fed from a power source to the windings in the electromagnets of the electromagnetic brake. This is accomplished by any current limiting device controlled by an out-signal from the control unit 44. Alternatively, it the electromagnet is connected to a power source where the voltage is controlled, the voltage is controlled by the out-signal from the control unit thus indirectly controlling the amperage of the current in the magnet windings. For a brake comprising permanent magnets in place of electromagnets the magnetic flux density is controlled by the distance between the front end of the magnets and the mold and/or by the material present between the magnets and the mold.

The flow pattern illustrated in figure 5 is typically developed for a method where a primary flow p of the hot melt enters the mold through side ports of a submerged entry nozzle and a brake is adapted to apply magnetic fields to act on the metal in the mold in a magnetic band area H at a level downstream the side ports. The width of the magnetic band area H covers preferably as shown in figure 5 essentially the whole width of the cast product. This configuration of the magnetic band area H, provides a significant circulating secondary flow C1 and C2 in the top end of the which is monitored by flow sensors 43. Downstream of the magnetic band area H might also a less stable circulating flow c3 and c4 develop, but the secondary flow is when casting according to the embodiment illustrated in figure 5 characterized by the braking and split of the primary flow caused by magnetic band area H resulting in a stable secondary flow C1 and C2 created by the cooperation of magnetic forces, induced

currents and the momentum of the primary flow in the mold. In the situation shown in figure 5 is preferably the secondary flow C1 and C2 supervised by monitoring them, using suitable sensors 43 located either at the meniscus, at the narrow side or by monitoring the standing wave. The magnetic flux density is preferably regulated to maintain the flow C1 and C2 within preset limits, but at times it might prove favorable to regulated the magnetic flux density such that the polarity of one or both magnetic band areas is reversed. By arranging the sensors 43 for monitoring the flows C1 and C2 separately the flows C1 and C2 can also be controlled independently provided that the magnetic field forces acting on the melt can be controlled for each half of the mold.

According to an alternative embodiment used in a similar mold and also for closed casting, the magnetic fields is applied to act in a magnetic band area F at a level with the side ports openings of the submerged entry nozzle. The width of the magnetic band area F covers, also according to this embodiment, essentially the whole width of the cast product. With the configuration of the magnetic band area F as shown in figure 6 a good braking of the primary flow p is obtained in combination with the development of a stable secondary flow G1 and G2 in a region below the band area F which is supplemented by smaller but stable secondary flows g3 and g4 in the upper part of the mold, i.e. above band area F. Also in this situation is preferably the main secondary flow, i.e. G1 and G2 supervised preferably by monitoring it at the narrow side using suitable sensors 45. But also the minor flow at the top end g3 and g4 needs to be monitored using suitable sensors 43. The magnetic flux density of the magnetic field acting in band area D is preferably regulated. Preferably both the flow G1 and G2 and the flow g3 and g4 is maintained within preset limits, but at times it might prove favorable to regulated the magnetic flux density such that the polarity of one or both magnetic band areas is reversed. By arranging sensors 45 for monitoring the flows G1 and G2 separately the flows G1 and G2 can also be controlled independently the mold provided that the magnetic field forces acting on the melt can be controlled for each half of the mold. The same goes for g3 and g4.

The flow pattern illustrated in figure 7 is typically developed for a method according to figure 5 supplemented by a substantial purge of a gas such as argon within the

nozzle. Thus the primary flow p of the hot melt which enters the mold through side ports of the submerged entry nozzle is acted on by the gas-bubbles (Ar) and by the magnetic fields applied to act on the metal in the mold in a magnetic band area K at a level downstream the side ports. The width of the magnetic band area K covers preferably as shown in figure 5 essentially the whole width of the cast product. This configuration of the magnetic band area K combined with the upward flow of bubbles (Ar) along the nozzle surface, provides a significant circulating secondary flow O1 and O2 in the top end of the which is reversed, i.e. it is directed upward in the center of the mold flows outward towards the narrow sides at the meniscus, downward along the narrow sides and inward above the magnetic band area K. The reversed flow O1 and O2 is monitored by flow sensors 43. Downstream of the magnetic band area K might also a less stable circulating flow c3 and c4 develop, which might be either reversed or normal. The secondary flow is when casting according to the embodiment illustrated in figure 7, using gas purging in the nozzle, characterized by the braking and split of the primary flow caused by magnetic band area K in combination with the flow of gas bubbles (Ar) resulting in a stable secondary flow C1 and C2 created by the cooperation of magnetic forces, induced currents, gas bubbles (Ar) and the momentum of the primary flow in the region at the nozzle ports. In the situation shown in figure 7 is preferably the reversed secondary flow O1 and O2 supervised by monitoring them, using suitable sensors 43 located either at the meniscus, at the narrow side or by monitoring the standing wave. The magnetic flux density is preferably regulated to maintain the reversed flow-pattern and also the flow velocities of O1 and O2 within preset limits, but at times it might prove favorable to regulated the magnetic flux density such that the polarity of one or both magnetic band areas is reversed. By arranging the sensors 43 for monitoring the flows O1 and O2 separately the flows O1 and O2 can also be controlled independently provided that the magnetic field forces acting on the melt can be controlled for each half of the mold.

The flow pattern illustrated in figure 8 is typically developed for a method where a primary flow p of the hot melt enters the mold through side ports of a submerged entry nozzle a brake is adapted to apply magnetic fields to act on the metal in the mold;

- at two zones LI, LII in a first magnetic band area L at a level with the meniscus or at a level between the meniscus and the side ports, the two zones being located at the sides of the nozzle; and
- at two zones NI, NII in a second magnetic band area N at a level downstream the side ports, the two zones being located at the sides of the nozzle.

For control purposes the mold is split in half in the casting direction in such a way that it comprises two control zones I, II, where control zone I comprises magnetic zones LI and NI and detection means 43a, 45a for monitoring the flow in this zone I and control zone II comprises magnetic zones LII and NII and detection means 43b, 45b for monitoring the flow in this zone II. Using two control zones ensures that an essentially symmetrical and balanced two-loop flow is developed in the upper part of the mold. Thereby the risks of an unsymmetrical, unbalanced so called biased two-loop flow is developed or even in the extreme case transforming into an undesired one-loop flow, where the melt flows up along one molds side, across the meniscus to the other side, down and further back across the mold at level N, is eliminated. A biased flow increases the risks for turbulence and vortexes at the meniscus and thus affects the cleanliness of the metal as the removal of non-metallic particles, gas bubbles is impaired and the tendency for mold power to be drawn down into the metal is increased. The magnetic zones LI,LII,NI,NII are preferably as shown in figure 8 located such that a central area comprising the nozzle is essentially free from magnetic fields but also a method using magnetic zones with essentially the same width as the control zones I, II, i.e. which wholly or partly covers the nozzle will result in a similar secondary flow. This configuration of the magnetic zones LI,LII,NI,NII, provides a significant circulating secondary flow C1 and C2 in the top end of the mold, between the two levels L and N, which is similar to the flow in figure 2 and 5. The flow is monitored by flow sensors 43a,43b. Downstream of the second lower level N might also a less stable circulating flow c3 and c4 develop, but the secondary flow is when casting according to the embodiment illustrated in figure 8 is characterized by the braking and split of the primary flow caused by magnetic zones NI and NII resulting in a stable secondary flow C1 and C2 created by the cooperation of magnetic forces, induced currents and the momentum of the primary flow in the region between the two levels. In the situation shown in figure 8 is preferably the secondary flow C1 and C2 supervised by monitoring them, using suitable sensors 43a,43b located in both control

zones I, II either at the meniscus, at the narrow side or by monitoring the standing wave. The magnetic flux density of one or both of LI, NI is preferably regulated to maintain the flow C1 using sensors 43a for monitoring the flow C1 and the magnetic flux density of one or both of LII, NII is preferably regulated to maintain the flow C2 within preset limits using sensors 43b for monitoring the flow C2.

CLAIMS

1. A method for continuous or semi-continuous casting of metal, wherein a primary flow (P) of hot metallic melt supplied into a mold is acted upon by at least one static or periodically low-frequency magnetic field to brake and split the primary flow and form a controlled secondary flow pattern in the non-solidified parts of the cast strand and where the magnetic flux density of the magnetic field is controlled based on casting conditions, **characterized** in that the secondary flow (M,U,C1,C2,c3,c4,G1,G2,g3,g4,O1,O2,o3,o4) in the mold is monitored throughout the casting and that, upon detection of a change in the flow, information on the detected change monitored flow is fed into a control unit where the change is evaluated and that the magnetic flux density is regulated based on this evaluation to maintain or adjust the controlled secondary flow.

2. A method according to claim 1, **characterized** in that the flow velocity of the secondary flow (M,U,C1,C2,c3,c4,G1,G2,g3,g4,O1,O2,o3,o4) is measured continuously throughout essentially the whole casting in at least one specific point in the mold and that upon detection of a change said change is evaluated and that the magnetic flux density is regulated based on this evaluation.

3. A method according to claim 1, **characterized** in that the flow velocity of the secondary flow (M,U,C1,C2,c3,c4,G1,G2,g3,g4,O1,O2,o3,o4) is sampled throughout essentially the whole casting in at least one specific point in the mold and that upon detection of a change said change is evaluated and that the magnetic flux density is regulated based on this evaluation.

4. A method according any of claims 2 or 3, **characterized** in that the flow velocity at the meniscus ($v_m$) is monitored and that upon detection of a change said change is evaluated and that the magnetic flux density is regulated based on this evaluation to maintain the flow velocity at the meniscus ($v_m$) within a predetermined flow velocity range.

5. A method according to any of the preceding claims, **characterized** in that the flow velocity of the upwardly directed secondary flow ($v_u$) at one of the molds narrow sides is that

upon detection of a change said change is evaluated and that the magnetic flux density is regulated based on this evaluation.

6. A method according to any of the preceding claims, **characterized** in that the height ($h_w$), location and/or shape of a standing wave, which is generated on the meniscus by the upwardly directed secondary flow at one of the molds narrow sides, is monitored, that upon detection of a change said change is evaluated and that the magnetic flux density is regulated based on this evaluation.

7. A method according to any of the preceding claims, **characterized** in that the mold is split into two or more control zones (I,II), that the flow (P,M,U, O1,O2,o3,o4) is monitored within each control zone, that any detected change in the flow within a control zone is evaluated and that the magnetic flux density of a magnetic field influencing the flow within said control zone is regulated based on said evaluation.

8. A method according to claim 7, **characterized** in that the mold is split into two control zones (I,II), the two zones comprising the right and the left half of the mold respectively, that the flow (P,M,U, O1,O2,o3,o4) is monitored within each control zone, that any detected change in the flow within a control zone is evaluated and that the magnetic flux density of a magnetic field influencing the flow within said control zone is regulated based on said evaluation to maintain a symmetrical, balanced flow in the mold and suppress the tendency for unbalanced biased flow to develop.

9. A method according to any of claims 7 or 8, **characterized** in that the flow velocity at meniscus ($v_m$) is measured for each control zone.

10. A method according to any of claims 7 or 8, **characterized** in that the upwardly directed flow ($v_u$) at the narrow molds sides is monitored at both narrow mold sides.

11. A method according to any of claims 7 or 8, **characterized** in that the height ($h_w$), location and/or shape of a standing wave, which is generated on the meniscus by the

upwardly directed secondary flow at the narrow molds sides is monitored indirectly at both narrow mold sides.

12. A method according to any of the preceding claims, **characterized** in that a detected change is evaluated and the magnetic flux density is regulated using an algorithm comprised in the control unit (44).

13. A method according to any of claims 1 to 11, **characterized** in that a detected change is evaluated and the magnetic flux density is regulated using a statistical model comprised in the control unit (44).

14. A method according to any of claims 1 to 11, **characterized** in that a detected change is evaluated and the magnetic flux density is regulated using a method for data-analysis comprised in the control unit (44).

15. A method according to any of claims 12, 13 or 14, **characterized** in that one or more predetermined parameters out of the following group of parameters;
- mold dimensions,
- nozzle dimensions and nozzle configuration including the angle of the ports and immersion depth,
- dimensions, configuration and position of magnetic poles;
- composition of metal casted;
- composition of mold powder used, and
- flow of any gas purged,
is included in the algorithm, statistical model or method for data analysis used to evaluate the change to the flow and to regulate the magnetic flux density.

16. A method according to any of claims 12 to 15, **characterized** in that one or more further parameters, which are likely to change during casting are monitored throughout the casting and that the actual value of said parameter is included on-line in the algorithm,

statistical model or method for data analysis used to evaluate the determined change to the flow and to regulate the magnetic flux density.

17. A method according to any of claims 12 to 15, **characterized** in that one or more further parameters, which are likely to change during casting, is included as a function, of time or other parameter, in the algorithm, statistical model or method for data analysis used to evaluate the determined change to the flow and to regulate the magnetic flux density.

18. A method according to any of claims 16 or 17, **characterized** in that one or more out of the following group of parameters, which are likely to change during casting, is included in the algorithm, statistical model or method for data analysis used to evaluate the determined change to the flow and to regulate the magnetic flux density together with the monitored flow parameter;

- superheat of the metal upon entry in mold;
- ferrostatic pressure at nozzle exit;
- flow velocity of primary flow upon exit from nozzle;
- any gas bubbling in mold;
- casting speed;
- mold powder addition rate;
- position of meniscus in mold and relative nozzle port;
- position of nozzle port relative mold;
- position of magnetic field(s) relative meniscus and nozzle ports;
- direction of magnetic field; and
- any other casting parameter deemed critical for the secondary flow and which is likely to change during casting.

19. A method according to any of the preceding claims, **characterized** in that at least one magnetic field acting on the melt in the mold is generated by an electromagnetic brake (42) and that the amperage of the current supplied from a power source (421) to the winding of the electromagnetic brake is controlled thus the regulating the magnetic flux density of the magnetic field.

20. A method according to any of the preceding claims, **characterized** in that two or more magnetic fields are arranged to act on the metal in the mold.

21. A method according to claim 20, **characterized** in that the magnetic fields are disposed to act at two or more levels, one after the other, in the casting direction.

22. A method according to claim 21, **characterized** in that at least one first level (B,N) is disposed at level with or downstream the outlet port(s) of the nozzle and that at least one second level (A,L) is disposed at level with the meniscus or at a level between the meniscus and the nozzle port(s).

23. A method according to claim 21, **characterized** in that at least one first level (D) is disposed at level with the outlet port(s) of the nozzle and that at least one second level (E) is disposed at level downstream of said first level.

24. A method according to any of claims 20-23, **characterized** in that where the metal in the mold is acted on by two or more magnetic fields the magnetic flux densities of said fields are regulated independently of each other.

25. A method according to any of the preceding claims, **characterized** in that at least one alternating magnetic field is applied to act on the melt in the mold or in the strand downstream of the mold and that also the control unit is adopted to regulate also said alternating magnetic field on-line.

26. A device for continuous or semi-continuous casting of metals comprising a mold for forming a cast strand, means for supply of a primary flow (P) of a hot metallic melt to the mold and magnetic means (42) for application of at least one magnetic field to act upon the metal in the mold, **characterized** in that the magnetic means is associated with a control unit (44), said control unit is associated with detection means (43,43a, 43b, 45, 45a, 45b), that said detection means is adapted to monitor the secondary flow (M,U,C1,C2,c3,c4,G1,G2,g3,g4, O1, O2,o3,o4) in the mold and to detect any changes in said flow, and that said control unit

comprises evaluation means to evaluate said detected change and control means to regulate the magnetic flux density of the magnetic field based on the evaluation of the detected change in said flow.

27. A device according to claim 26, **characterized** in that the mold comprises control zones (I,II), which split the mold, and that each control zone comprises detection means (43a,43b, 45a,45b) associated with the control unit (44) and the magnetic means (42) influencing the flow within the zone.

28. A device according to claim 27, **characterized** in that the mold comprises two control zones (I,II), the two control zones comprising the right and the left half of the mold, respectively.

29. A device according to any of claims 26-28, **characterized** in that detection means (43,43a,43b,45,45a,45b) comprises a magnetic flow-meter based on eddy-current technique or comprising a permanent magnet to measure and monitor the flow velocity and that the detection means is associated with a control unit (44) comprising suitable software in the form of an algorithm, a statistical model or multivariate data-analysis method for correlation of the measurements with the flow. .

30. A device according to any of claims 26-28, **characterized** in that the detection means (43,43a,43b,45,45a,45b) comprises at least one temperature that the detection means is associated with a control unit (44) comprising suitable software in the form of an algorithm, a statistical model or multivariate data-analysis method for correlation of the temperature measurements with the flow.

31. A device according to any of claims 26-28, **characterized** in that the detection means (43,43a,43b,45,45a,45b) comprises a magnetic device for level-control based on eddy-current technique or comprising a permanent magnet to monitor the height ($h_w$), location and/or shape of the standing wave generated by the upward flow at the meniscus and that the detection means is associated with a control unit (44) comprising suitable software in the form of an

algorithm, a statistical model or multivariate data-analysis method for correlation of the meniscus profile measurements with the flow.

32. A device according to any of claims 26-31, **characterized** in that the control unit (44) comprises a neural network.

33. A device according to any of claims 26-32, **characterized** in that the control unit (44) comprises an electronic device with soft-ware in the form of a algorithm, statistical model or multivariate data-analysis for processing of casting parameters and means for regulating the magnetic flux density based on the result of said processing.

34. A device according to any of claims 26-33, **characterized** in that a plurality of electro-magnets (42) is arranged to apply magnetic fields to act in the form of magnetic band areas at one or more level disposed one after the other in the casting direction and a controlled unit (44) is associated with electromagnets to regulate the magnetic flux density in at least one band area.

35. A device according to claim 34, **characterized** in that one control unit (44) is associated with two or more pairs of magnets (42) to regulate the magnetic field(s) applied by them.

36. A device according to claim 34, **characterized** in that the electromagnetic brake device is associated to two or more control units (44), each unit connected to at least one pair of magnets (42), such that at least one pair of magnets can be controlled independently of the other pair(s).

37. A device according to any of claims 26-36, **characterized** in that the control unit (44) is associated to a further electromagnetic device arranged to apply a alternating electromagnetic field to act on the melt in the mold or to the melt in the strand downstream of the mold to regulate the magnetic field generated by said device.

## AMENDED CLAIMS

[received by the International Bureau on 1 February 1999 (01.02.99); original claims 1-3, 5 and 26 amended; remaining claims unchanged (7 pages)]

1. A method for continuous or semi-continuous casting of metal, wherein a primary flow (P) of hot metallic melt supplied into a mold is acted upon by at least one static or periodically low-frequency magnetic field to brake and split the primary flow and form a controlled secondary flow pattern in the non-solidified parts of the cast strand and where the magnetic flux density of the magnetic field is controlled based on casting conditions, **characterized** in that the secondary flow (M,U,C1,C2,c3,c4,G1,G2,g3,g4,O1,O2,o3,o4) in the mold is monitored throughout essentially the whole casting and that, upon detection of a change in the flow, information on the detected change in the monitored flow is fed into a control unit where the change is evaluated and that thereafter the magnetic flux density is regulated essentially on-line based on this evaluation to maintain or adjust the controlled secondary flow.

2. A method according to claim 1, **characterized** in that the flow velocity of the secondary flow (M,U,C1,C2,c3,c4,G1,G2,g3,g4,O1,O2,o3,o4) is measured continuously at least one specific point in the mold.

3. A method according to claim 1, **characterized** in that the flow velocity of the secondary flow (M,U,C1,C2,c3,c4,G1,G2,g3,g4,O1,O2,o3,o4) is sampled in at least one specific point in the mold.

4. A method according any of claims 2 or 3, **characterized** in that the flow velocity at the meniscus ($v_m$) is monitored and that upon detection of a change said change is evaluated and that the magnetic flux density is regulated based on this evaluation to maintain the flow velocity at the meniscus ($v_m$) within a predetermined flow velocity range.

5. A method according to any of the preceding claims, **characterized** in that the flow velocity of the upwardly directed secondary flow ($v_u$) at one of the molds narrow sides is monitored and that upon detection of a change said change is evaluated and that the magnetic flux density is regulated based on this evaluation to maintain and adjust the flow velocity of this upwardly directed flow ($v_u$).

6. A method according to any of the preceding claims, **characterized** in that the height ($h_w$), location and/or shape of a standing wave, which is generated on the meniscus by the upwardly directed secondary flow at one of the molds narrow sides, is monitored, that upon detection of a change said change is evaluated and that the magnetic flux density is regulated based on this evaluation.

7. A method according to any of the preceding claims, **characterized** in that the mold is split into two or more control zones (I,II), that the flow (P,M,U, O1,O2,o3,o4) is monitored within each control zone, that any detected change in the flow within a control zone is evaluated and that the magnetic flux density of a magnetic field influencing the flow within said control zone is regulated based on said evaluation.

8. A method according to claim 7, **characterized** in that the mold is split into two control zones (I,II), the two zones comprising the right and the left half of the mold respectively, that the flow (P,M,U, O1,O2,o3,o4) is monitored within each control zone, that any detected change in the flow within a control zone is evaluated and that the magnetic flux density of a magnetic field influencing the flow within said control zone is regulated based on said evaluation to maintain a symmetrical, balanced flow in the mold and suppress the tendency for unbalanced biased flow to develop.

9. A method according to any of claims 7 or 8, **characterized** in that the flow velocity at meniscus ($v_m$) is measured for each control zone.

10. A method according to any of claims 7 or 8, **characterized** in that the upwardly directed flow ($v_u$) at the narrow molds sides is monitored at both narrow mold sides.

11. A method according to any of claims 7 or 8, **characterized** in that the height ($h_w$), location and/or shape of a standing wave, which is generated on the meniscus by the upwardly directed secondary flow at the narrow molds sides is monitored indirectly at both narrow mold sides.

12. A method according to any of the preceding claims, **characterized** in that a detected change is evaluated and the magnetic flux density is regulated using an algorithm comprised in the control unit (44).

13. A method according to any of claims 1 to 11, **characterized** in that a detected change is evaluated and the magnetic flux density is regulated using a statistical model comprised in the control unit (44).

14. A method according to any of claims 1 to 11, **characterized** in that a detected change is evaluated and the magnetic flux density is regulated using a method for data-analysis comprised in the control unit (44).

15. A method according to any of claims 12, 13 or 14, **characterized** in that one or more predetermined parameters out of the following group of parameters;
- mold dimensions,
- nozzle dimensions and nozzle configuration including the angle of the ports and immersion depth,
- dimensions, configuration and position of magnetic poles;
- composition of metal casted;
- composition of mold powder used, and
- flow of any gas purged,

is included in the algorithm, statistical model or method for data analysis used to evaluate the change to the flow and to regulate the magnetic flux density.

16. A method according to any of claims 12 to 15, **characterized** in that one or more further parameters, which are likely to change during casting are monitored throughout the casting and that the actual value of said parameter is included on-line in the algorithm, statistical model or method for data analysis used to evaluate the determined change to the flow and to regulate the magnetic flux density.

17. A method according to any of claims 12 to 15, **characterized** in that one or more further parameters, which are likely to change during casting, is included as a function, of time or other parameter, in the algorithm, statistical model or method for data analysis used to evaluate the determined change to the flow and to regulate the magnetic flux density.

18. A method according to any of claims 16 or 17, **characterized** in that one or more out of the following group of parameters, which are likely to change during casting, is included in the algorithm, statistical model or method for data analysis used to evaluate the determined change to the flow and to regulate the magnetic flux density together with the monitored flow parameter;

- superheat of the metal upon entry in mold;
- ferrostatic pressure at nozzle exit;
- flow velocity of primary flow upon exit from nozzle;
- any gas bubbling in mold;
- casting speed;
- mold powder addition rate;
- position of meniscus in mold and relative nozzle port;
- position of nozzle port relative mold;
- position of magnetic field(s) relative meniscus and nozzle ports;
- direction of magnetic field; and
- any other casting parameter deemed critical for the secondary flow and which is likely to change during casting.

19. A method according to any of the preceding claims, **characterized** in that at least one magnetic field acting on the melt in the mold is generated by an electromagnetic brake (42) and that the amperage of the current supplied from a power source (421) to the winding of the electromagnetic brake is controlled thus the regulating the magnetic flux density of the magnetic field.

20. A method according to any of the preceding claims, **characterized** in that two or more magnetic fields are arranged to act on the metal in the mold.

21. A method according to claim 20, **characterized** in that the magnetic fields are disposed to act at two or more levels, one after the other, in the casting direction.

22. A method according to claim 21, **characterized** in that at least one first level (B,N) is disposed at level with or downstream the outlet port(s) of the nozzle and that at least one second level (A,L) is disposed at level with the meniscus or at a level between the meniscus and the nozzle port(s).

23. A method according to claim 21, **characterized** in that at least one first level (D) is disposed at level with the outlet port(s) of the nozzle and that at least one second level (E) is disposed at level downstream of said first level.

24. A method according to any of claims 20-23, **characterized** in that where the metal in the mold is acted on by two or more magnetic fields the magnetic flux densities of said fields are regulated independently of each other.

25. A method according to any of the preceding claims, **characterized** in that at least one alternating magnetic field is applied to act on the melt in the mold or in the strand downstream of the mold and that also the control unit is adopted to regulate also said alternating magnetic field on-line.

26. A device for continuous or semi-continuous casting of metals comprising a mold for forming a cast strand, means for supply of a primary flow (P) of a hot metallic melt to the mold and magnetic means (42) for application of at least one magnetic field to act upon the metal in the mold, **characterized** in that the magnetic means is associated with a control unit (44), said control unit is associated with detection means (43,43a, 43b, 45, 45a, 45b), that said detection means is adapted to monitor the secondary flow (M,U,C1,C2,c3,c4,G1,G2,g3,g4, O1, O2,o3,o4) in the mold and to detect any changes in said flow, and that said control unit comprises evaluation means to evaluate said detected change and control means to regulate essentially on-line the magnetic flux density of the magnetic field based on the evaluation of the detected change in said flow.

27. A device according to claim 26, **characterized** in that the mold comprises control zones (I,II), which split the mold, and that each control zone comprises detection means (43a,43b, 45a,45b) associated with the control unit (44) and the magnetic means (42) influencing the flow within the zone.

28. A device according to claim 27, **characterized** in that the mold comprises two control zones (I,II), the two control zones comprising the right and the left half of the mold, respectively.

29. A device according to any of claims 26-28, **characterized** in that detection means (43,43a,43b,45,45a,45b) comprises a magnetic flow-meter based on eddy-current technique or comprising a permanent magnet to measure and monitor the flow velocity and that the detection means is associated with a control unit (44) comprising suitable software in the form of an algorithm, a statistical model or multivariate data-analysis method for correlation of the measurements with the flow. .

30. A device according to any of claims 26-28, **characterized** in that the detection means (43,43a,43b,45,45a,45b) comprises at least one temperature that the detection means is associated with a control unit (44) comprising suitable software in the form of an algorithm, a statistical model or multivariate data-analysis method for correlation of the temperature measurements with the flow.

31. A device according to any of claims 26-28, **characterized** in that the detection means (43,43a,43b,45,45a,45b) comprises a magnetic device for level-control based on eddy-current technique or comprising a permanent magnet to monitor the height ($h_w$), location and/or shape of the standing wave generated by the upward flow at the meniscus and that the detection means is associated with a control unit (44) comprising suitable software in the form of an algorithm, a statistical model or multivariate data-analysis method for correlation of the meniscus profile measurements with the flow.

32. A device according to any of claims 26-31, **characterized** in that the control unit (44) comprises a neural network.

33. A device according to any of claims 26-32, **characterized** in that the control unit (44) comprises an electronic device with soft-ware in the form of a algorithm, statistical model or multivariate data-analysis for processing of casting parameters and means for regulating the magnetic flux density based on the result of said processing.

34. A device according to any of claims 26-33, **characterized** in that a plurality of electromagnets (42) is arranged to apply magnetic fields to act in the form of magnetic band areas at one or more level disposed one after the other in the casting direction and a controlled unit (44) is associated with electromagnets to regulate the magnetic flux density in at least one band area.

35. A device according to claim 34, **characterized** in that one control unit (44) is associated with two or more pairs of magnets (42) to regulate the magnetic field(s) applied by them.

36. A device according to claim 34, **characterized** in that the electromagnetic brake device is associated to two or more control units (44), each unit connected to at least one pair of magnets (42), such that at least one pair of magnets can be controlled independently of the other pair(s).

37. A device according to any of claims 26-36, **characterized** in that the control unit (44) is associated to a further electromagnetic device arranged to apply a alternating electromagnetic field to act on the melt in the mold or to the melt in the strand downstream of the mold to regulate the magnetic field generated by said device.

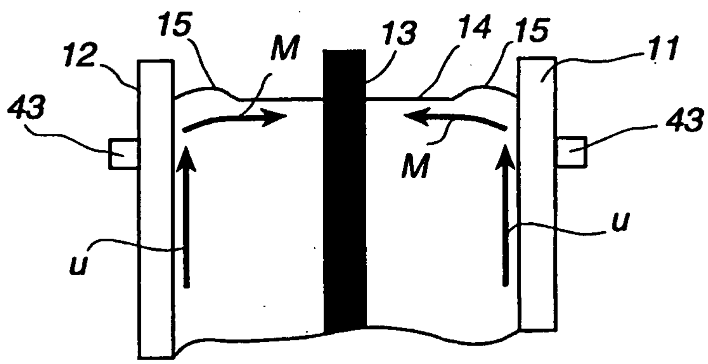



Fig 1

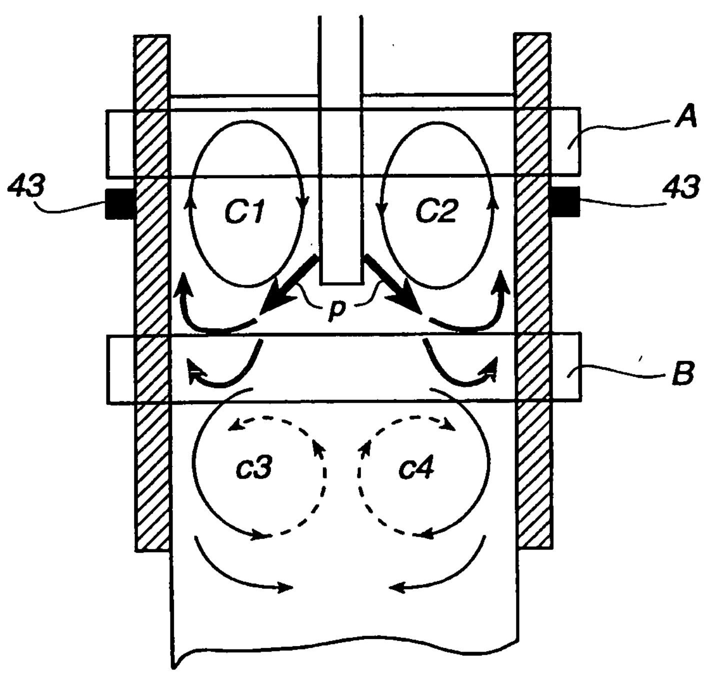



Fig 2

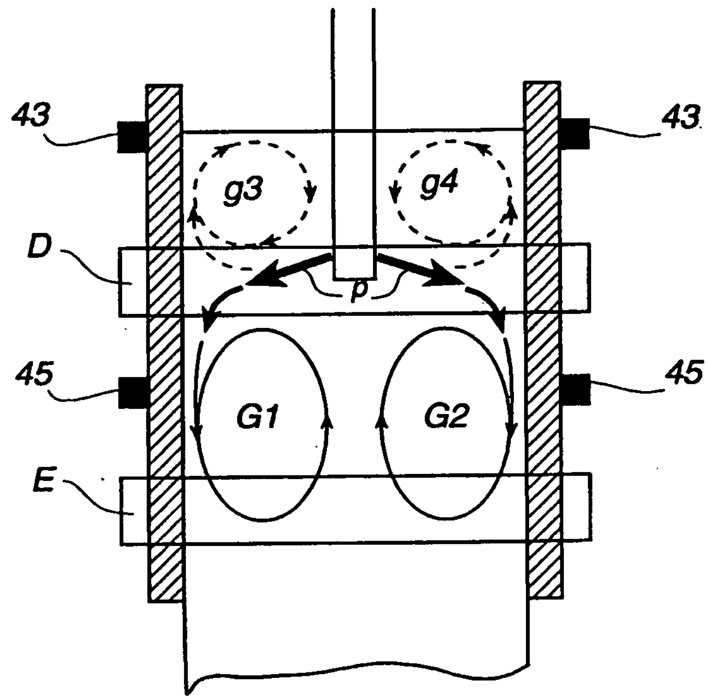



Fig 3

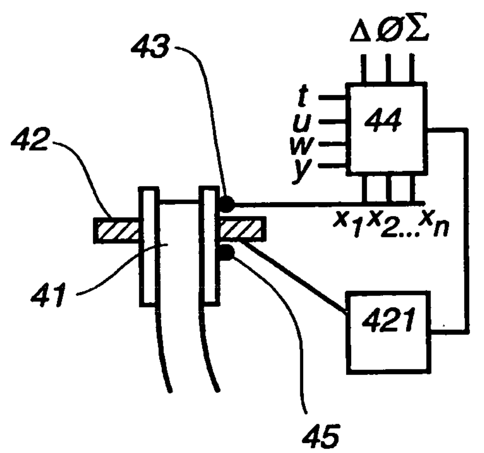



Fig 4

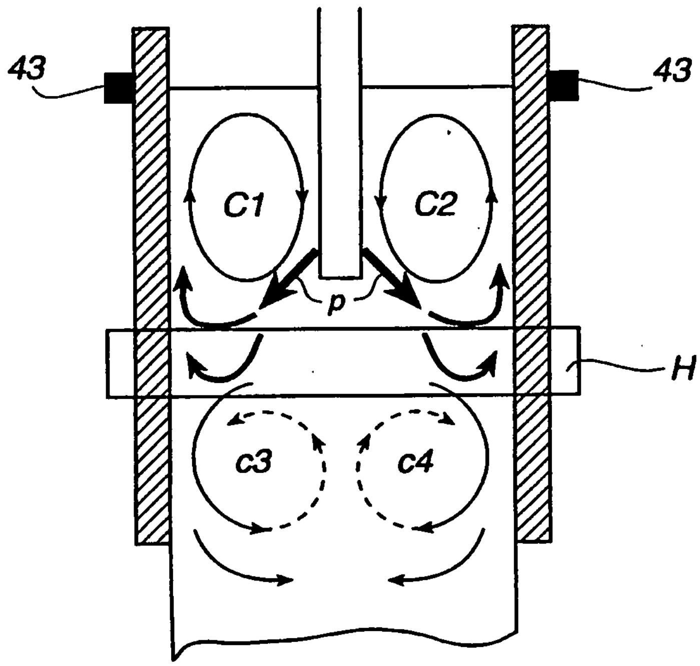



Fig 5

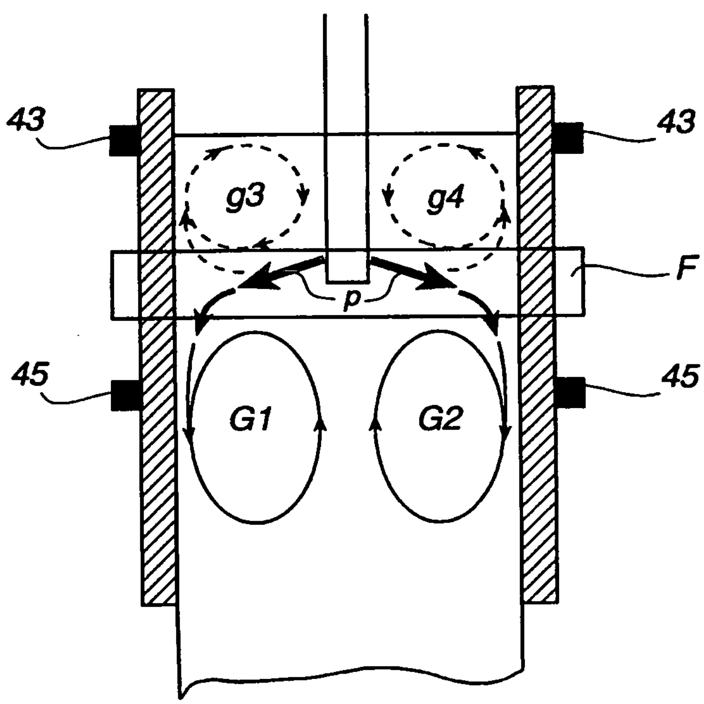
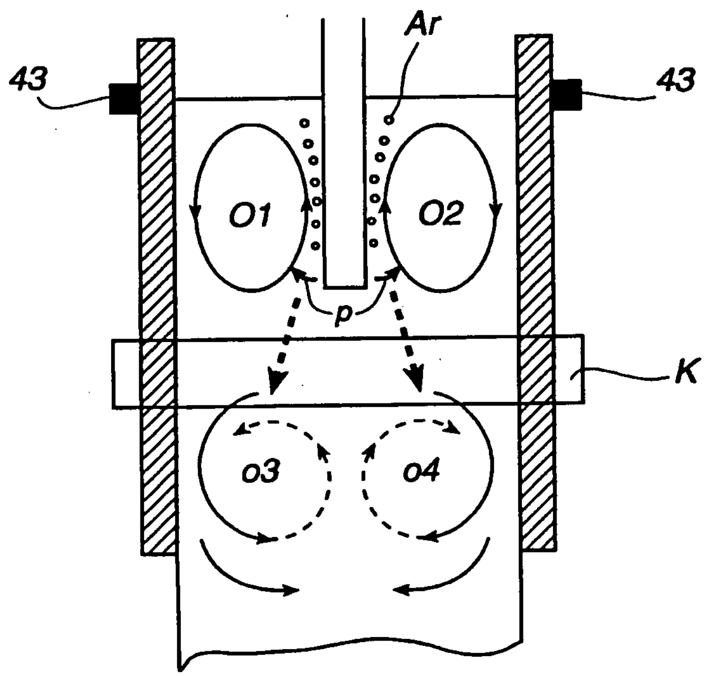
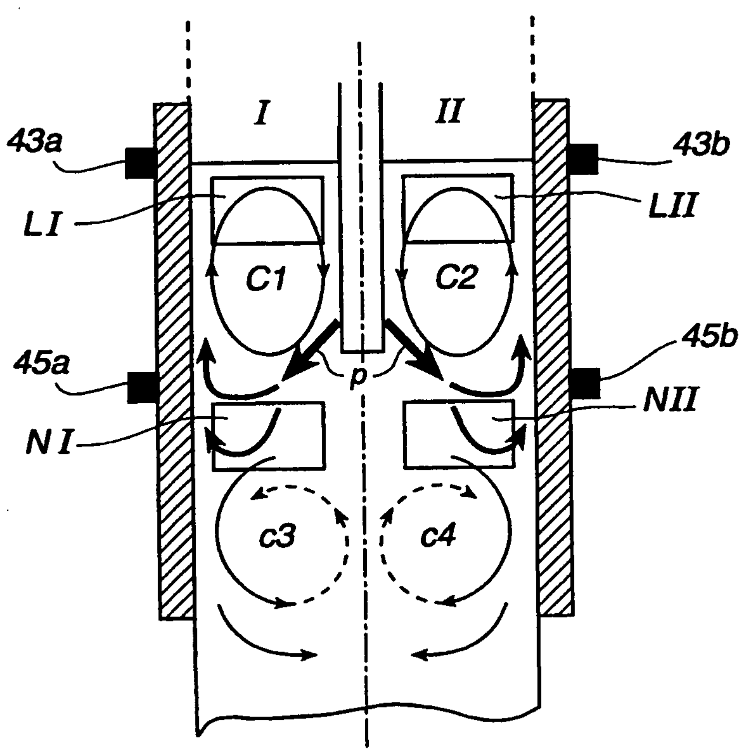



Fig 6



Ar
43
43
O1
O2
p
K
o3
o4


Fig 7



I
II
43a
43b
LI
LII
C1
C2
45a
45b
p
NII
NI
c3
c4


Fig 8

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/01547

## A. CLASSIFICATION OF SUBJECT MATTER

IPC6: B22D 11/10 // B22D 27/02

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: B22D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 22 December 1998 | 30 -12- 1998 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| Swedish Pat nt Offic<br>Box 5055, S-102 42 STOCKHOLM<br>Facsimile No. +46 8 666 02 86 | Ulf Nyström<br>Telephone No. +46 8 782 25 00 |

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/01547

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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01/12/98

International application No.
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